Background MC Production Status

John Stupak
on behalf of the Energy Frontier MC Production Team

8/30/21

Background

- EF simulation wiki: https://snowmass21.org/montecarlo/energy
- MC Task Force: Background, charge, etc
  - Responsible for developing MC production plan
  - Membership:

Name	Institution	email	
John Stupak (chair)	University of Oklahoma	john.stupak[at]cern.ch	Snowmass 2013
Robert Gardner	University of Chicago	rwg[at]uchicago.edu	OSG rep.
Simone Pagan Griso	LBNL	spagangriso[at]lbl.gov	BSM rep.
Stefan Hoeche	FNAL	shoeche[at]fnal.gov	MC expert
Fabio Maltoni	CP3, Catholic University of Louvain	maltoni.fabio[at]gmail.com	MC expert
Meenakshi Narain	Brown University	meenakshi.narain[at]cern.ch	EF convener
Isabel Ojalvo	Princeton University	isabel.rose.ojalvo[at]cern.ch	EWK rep.
Laura Reina	Florida State University	reina[at]hep.fsu.edu	EF convener
Michael Schmitt	Northwestern University	m-schmitt[at]northwestern.edu	QCD rep.
Alessandro Tricoli	Brookhaven National Laboratory	atricoli[at]bnl.gov	EF convener

The Plan

- Production of SM background MC samples to be carried out by the EF MC Production Team

Name	Institution	email
John Stupak (chair)	University of Oklahoma	john.stupak[at]cern.ch
Chris Hayes	University of Michigan	hayeschr[at]umich.edu
Federica Legger	INFN Turin	federica.legger[at]to.infn.it
Andrew Melo	Vanderbilt University	andrew.m.melo[at]vanderbilt.edu
Pascal Paschos	University of Chicago	paschos[at]uchicago.edu
Horst Severini	University of Oklahoma	severini[at]ou.edu
Giordon Stark	University of California Santa Cruz	gstark[at]cern.ch
Patricia Rebello Teles	Rio de Janeiro State University	patricia.rebello.teles[at]cern.ch
Chris Walker	University of Oklahoma	walker[at]nhn.ou.edu
David Yu	Brown University	david_yu[at]brown.edu

For variety of (understandable) reasons, we have lost half these folks to attrition

Just 2 physicists actively developing production workflow
(others contributing indirectly)

VOLUNTEERS NEEDED:
https://forms.gle/NRvUTBvCHHcuNq1g7

The Plan

- Production of SM background MC samples will be carried out by the EF MC Production Team
- Goal - support studies for these future detector benchmarks:

Machine	Energy						
Circular ee	m_Z	$2m_W$	240	$2m_t$			
ILC	250	350	500	1000			GeV
CLIC					1500	3000	
HL-LHC/FCC-hh	14	75	100	150			
LHeC/FCC-eh	1.3	3.5					TeV
μμ	3	6	10	14	30		

The Plan

- Production of SM background MC samples will be carried out by the EF MC Production Team
- Procedure:
    - hh samples will be generated proactively
    - ee, eh, and μμ samples will be generated on demand - No requests so far

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If no one asks for it, it won't get produced

MC requests can be made here

Snowmass Connect

- OSG has kindly offered to support Snowmass and supply computing resources
  - Interactive login node + batch job submission + storage
- Background MC will be produced and hosted on Snowmass Connect
- These resources are also available for ***any*** Snowmass use case
  - Signal MC production, analysis jobs, etc.
    - We only ask that before submitting a large batch of jobs, discuss workflow with OSG computing folks to ensure workflow is okay
  - Request an account here
  - Documentation is available here
  - See Slack for support and discussion

Please use these resources!

Signal Production

- Signal production is specialized and not very resource intensive → no need to centralize
  - MC Production Team will provide instructions to generate signal MC samples with the same parameters as the background samples, but will not directly produce signal MC
- If available computing resources are not sufficient, users can utilize the Open Science Grid (OSG)

Full Simulation

- Not producing any full sim samples
  - All of the future collider study groups will permit outside collaborators access to existing full-simulation samples
    - Minor impositions: Generally, abide by publication rules (present and discuss preliminary results at internal study group meetings)
  - Generally willing to produce (limited) new MC samples, if needed (and strongly-motivated)
    - Needs/motivation should be discussed with relevant Topical Group Conveners → MC Production Team → future collider study group MC Contact

Full Simulation

- Usage of "foreign" MC/simulation framework involves some degree of a learning curve
    - MC Task Force organized MC/Simulation Framework Tutorial Series to facilitate this process
        - Recorded for posterity (linked from timetable contributions)

Machine	Date	Link
ILC	Aug 28	https://indico.fnal.gov/event/45031/
CEPC	Sept 8	https://indico.fnal.gov/event/45183/
FCC-ee/hh	Sept 22-23	https://indico.cern.ch/event/945608/
Whizard for e+e-	Sept 28	https://indico.fnal.gov/event/45413/
FCC-ee/hh	Sept 29	https://indico.cern.ch/event/949950/
Muon Collider	Sep 30	https://indico.fnal.gov/event/45187/
LHeC/FCC-eh	Oct 13	https://indico.fnal.gov/event/45185/
ILC Analysis Walkthrough	Oct 14	https://indico.fnal.gov/event/45721/

Fast Simulation

- Delphes is widely-used, well-known, fast, accurate enough for most studies
- Detector cards exist for all proposed machines (some only very recently developed - might be tweaked)
  - Details on “blessed” cards available on TF wiki
- Will use Delphes for production of large SM background MC samples for all collider benchmarks
  - Will re-use existing truth-level events whenever possible

Hadron Colliders

- Need a coherent strategy to produce wide set of representative SM backgrounds with sufficient statistics in tails of many distributions, with minimal complexity/book keeping
  - Will use similar strategy to that adopted for Snowmass 2013
    - Combine processes with similar cross sections in single MC sample
    - On-shell internal propagators excluded → fully orthogonal
    - ~~Slice each sample in H_T~~ → Bias matrix element generation to large H_T
    - On-shell heavy resonances treated as stable
      - Subsequently decayed democratically using ~~BRIDGE~~ → MadSpin
    - Store event weight: σ_{LO} * NLO k-factor * w_{BR}

Dataset name	Physics process	Number of recoil jets
Bj-4p	γ or on-shell W, Z	1-3
Bjj-vbf-4p	γ or off-shell W, Z, H in VBF topology	2-3
BB-4p	Diboson (γ, W, Z) processes	0-2
BBB-4p	Tri-boson (γ, W, Z) processes including BH	0-1
LL-4p	Non-resonant dileptons (including neutrinos) with $m_{ll} > 20$ GeV	0-2
LLB-4p	Non-resonant dileptons with an on-shell boson, $m_{ll} > 20$ GeV	0-1
H-4p	Higgs	0-3
tj-4p	Single top (s- and t-channel)	0-2
tB-4p	Single top associated with a boson	0-2
tt-4p	$t\bar{t}$ pair production	0-2
ttB-4p	$t\bar{t}$ associated with γ, W, Z, H	0-1

Table 1-2. *Table of background processes. All processes include the particles in the dataset name plus additional recoil jets up to four generated particles. On-shell vector bosons, off-shell dileptons, Higgs bosons, top quarks, and jets are denoted B, LL, H, t, and j, respectively. In the Bjj-vbf-4p case, B includes Higgs.*

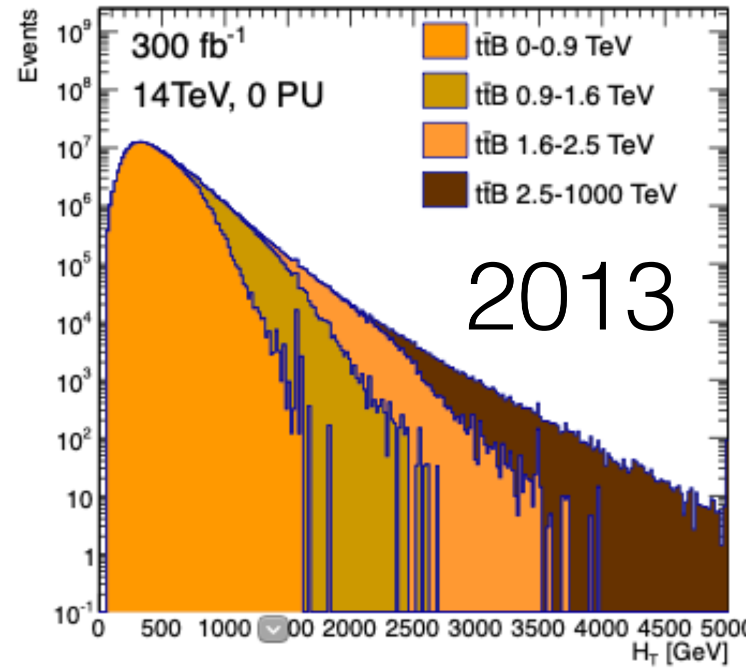
Proposed Workflow

- MadGraph: generate up to 4 partons at ME level with heavy resonances treated as stable - e.g. pp→tt, tt+j, tt+jj
- MadSpin: perform series of 1→N decays of heavy resonances - e.g. tt+jj→WbWb+jj→ffffbb+jj (8 parton final state)
- Pythia: showering and hadronization
- Delphes: detector simulation

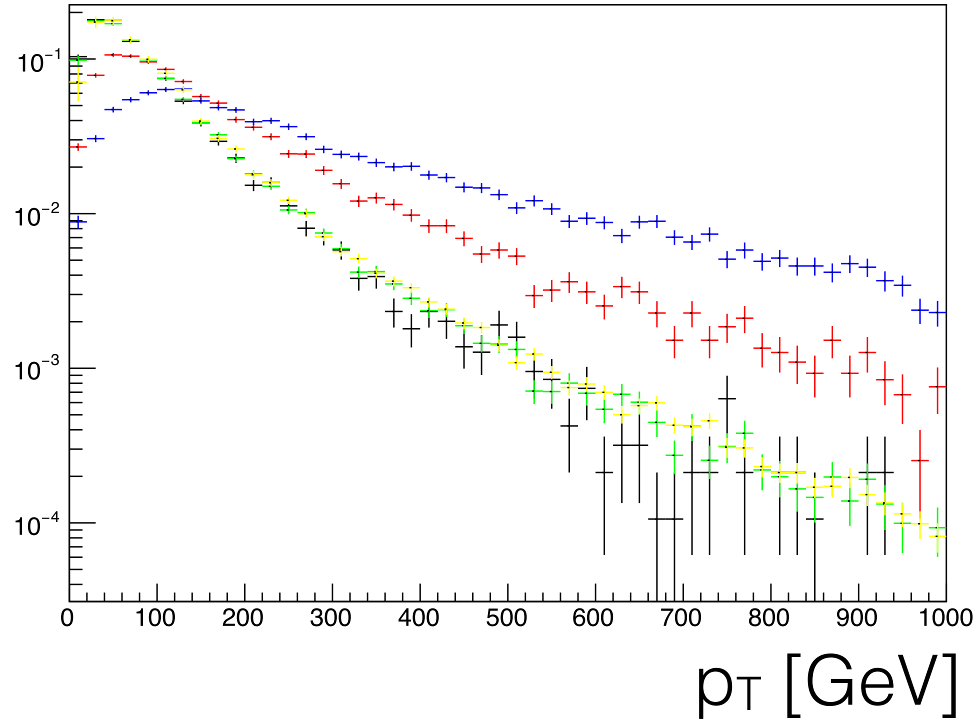
Version numbers: https://github.com/Snowmass21-software/MCProd/blob/main/install.sh

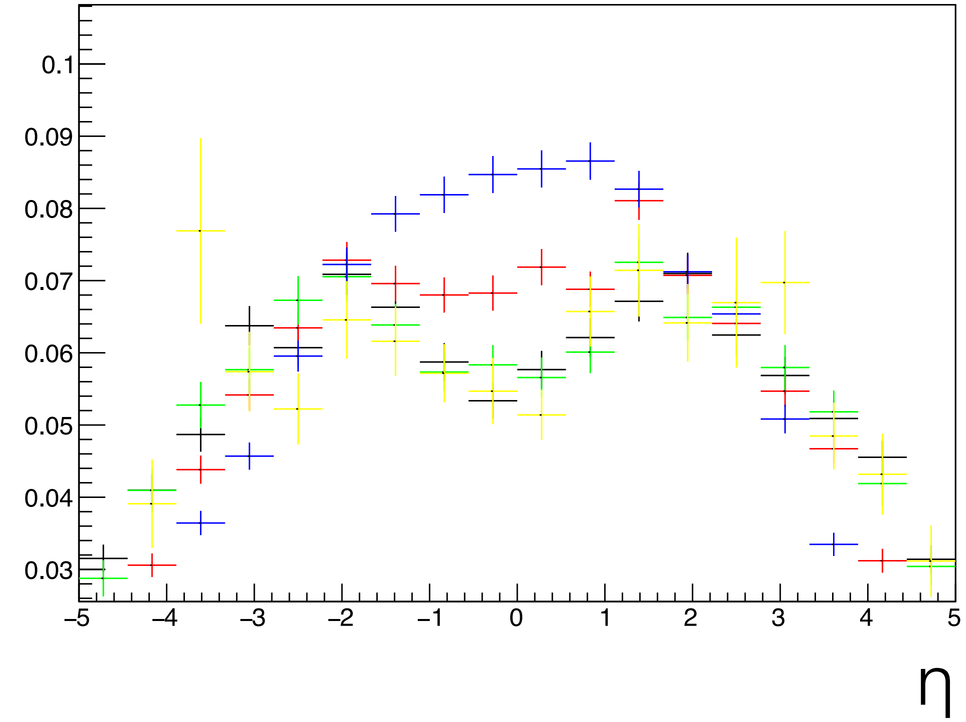
Bias

- Rather than slicing samples in $H_T \equiv \Sigma p_T$, artificially <u>bias ME generation</u> to large H_T
  - Recover physical H_T distribution via event weight
- Preliminary validation
  - BB sample - W boson kinematics:



no bias
H_T bias: raw
H_T^2 bias: raw
H_T bias: weighted
H_T^2 bias: weighted





MadSpin

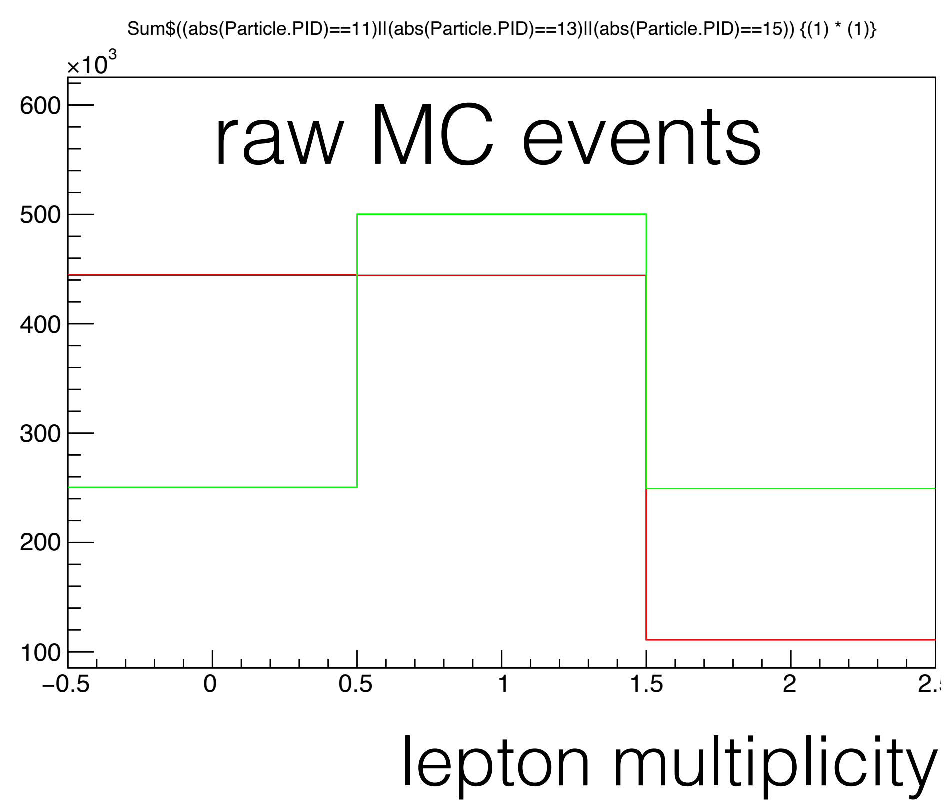
- Capable of preserving spin-correlations and finite width effects
- Devil is in the details
  - By default, only capable of 1→2 decays - can't decay H→4f
    - Dedicated mode for decaying scalars (no spin correlations or off-shell effects)
  - Can't combine MadSpin modes within a sample
    - Either decay t/W/Z with spin-correlations or decay H→4f, not both
    - Separate samples with H and t/W/Z?
      - What about VH? ttH?

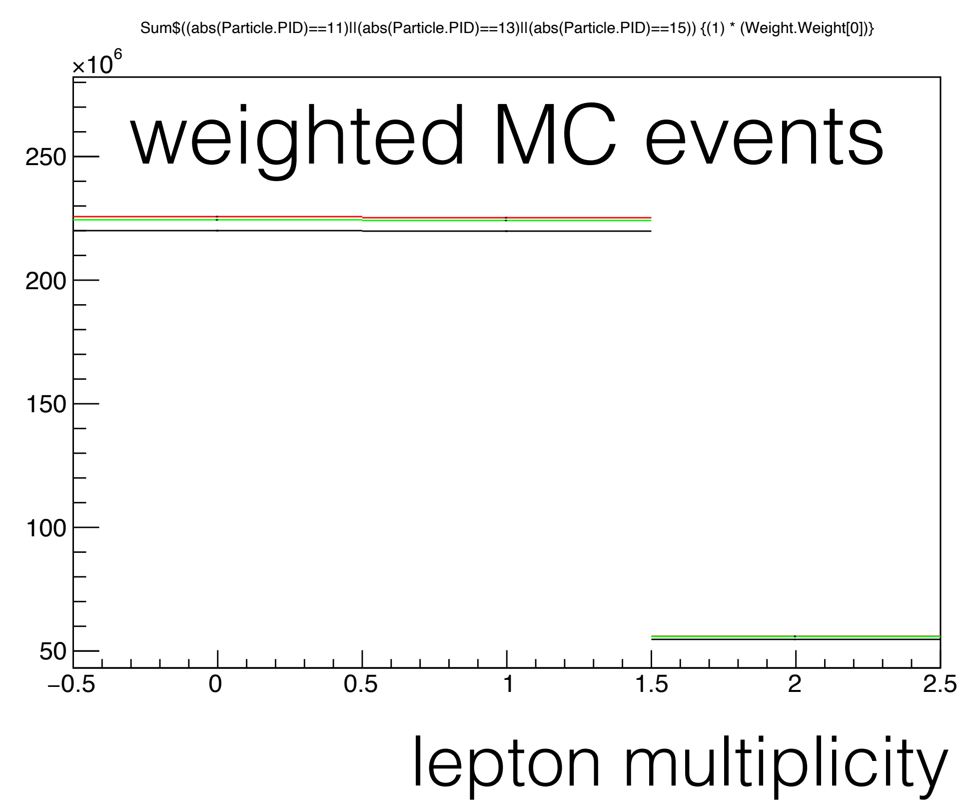
Rare Decays

- Also want to enhance statistics of "rare" decay modes (including W/Z→leptons)
    - Working with Olivier Mettelaer to develop/validate this capability (using MadSpin)
        - Initial approach only worked for W/Z/t decays
        - Now trying to apply a lepton multiplicity bias within MadSpin - WIP

ttbar sample:

MadGraph
MadSpin (B_{phys})
MadSpin (B_{demo})





Accuracy vs Precision

- Within a sample, forced to choose between either preserving spin correlations in W/Z/t decays, or enhancing H→4f statistics

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spin correlations	Enhanced H→4f statistics
B	H
VBF-B	VBF-H
BB	
BBB	VH?
LL	
LLB	
t	
tt	
tB	
ttB	ttH?

Proposed Workflow

- MadGraph: generate up to 4 partons at ME level
  - H_T bias
- MadSpin: perform series of $1 \rightarrow N$ decays
  - N_ℓ bias
- Pythia: showering and hadronization
- Delphes: detector simulation

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Further development and/or validation required

Not trivial to incorporate in gridpacks

Proposed Workflow

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Further development and/or validation required

Not trivial to incorporate in gridpacks

Short term: Prioritize production of vanilla samples

Current Workflow

NB: Even this workflow not validated yet

- MadGraph: generate up to 4 partons at ME level

No spin correlations

- Pythia: decay heavy resonances, showering and hadronization
- Delphes: detector simulation

Version numbers: https://github.com/Snowmass21-software/MCProd/blob/main/install.sh

Current Workflow

NB: Even this workflow not validated yet

- MadGraph: generate up to 4 partons at ME level

$$\sigma_B(100\ \mathrm{TeV}) = 10^{11}\ \mathrm{ab}$$

$$N = 10^{11}\ \mathrm{ab} \times 30\ \mathrm{ab}^{-1} = 3\mathrm{T\ MC\ events}$$

No spin correlations

- Pythia: decay heavy resonances, showering and hadronization

Never going to populate tails

- Delphes: detector simulation

VOLUNTEERS NEEDED:
https://forms.gle/NRvUTBvCHHcuNq1g7

Version numbers: https://github.com/Snowmass21-software/MCProd/blob/main/install.sh

Status

- Jobs have been running since Friday
  - First large-scale production → **NOT VALIDATED**
    - Please help!
  - Job submission/monitoring: SnowMass Monte Carlo framework [Andrew Melo]
  - Gridpacks: /project/data/snowmass2021/v0.1/
  - Generally using default cards
    - Exception: MadGraph - updated Higgs mass/BRs in param card to match LHCHXSWG recommendations
  - E = 13 and 100 TeV (FCC-hh Delphes card for both)
  - Output location: /collab/project/snowmass21/data/smmc (very soon!)
    - Working on http/web access
    - How to transfer data
  - ~8TB (35 million events?) available for: →
- More events on the way
  - Can generate ~12M events/day

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minor issue related to heft model - delay, not dealbreaker

Summary

- MC Production Task Force continued work throughout Snowmass "pause"
  - More person power needed to finish development and validate hh samples
    - **Volunteer**: https://forms.gle/NRvUTBvCHHcuNq1g7
- **EF simulation wiki**: https://snowmass21.org/montecarlo/energy
- Snowmass Connect:
  - MC location: /collab/project/snowmass21/data/smmc (very soon!)
  - Request an account here
  - Documentation is available here
  - See Slack for support and discussion
- Accepting requests for ee/eh samples through **Friday**, otherwise will scrap these plans

Backup

Additional Info

- Further details will be provided in a written document (forthcoming)
- EF MC wiki includes some useful info (will be expanded soon)
    - Summary of existing MC samples, details of full simulation frameworks, and contacts for each proposed collider:

Which proposed collider are you responding on behalf of?	What signal/background MC samples have been produced thus far (using either fast or full simulation)?	Where are they located?	Who within the collaboration should members of the Energy Frontier contact with further questions regarding MC/simulation frameworks?	Is there some place where additional information related to MC/simulation frameworks can be found?
ILC	generator-level event samples, stdhep format for √s = 250GeV, 350 GeV, 500 GeV, 1 TeV, further samples based on fast simultion (SGV) and full simulation (iLCSoft) are in preparation	On the GRID under VO ILC	jenny.list@desy.de	https://arxiv.org/abs/2007.03650
CLIC	See: https://twiki.cern.ch/twiki/bin/view/CLIC/MonteCarloSamplesForCLICdet	CERN EOS Storage	Please contact us at clicdp-snowmass-samples-contacts@cern.ch	https://arxiv.org/abs/1812.07337 contains a section on the software, github.com/ilcsoft
CEPC	We have full simulation of CEPC ZH and SM background at 240GeV, 350GeV, and Z pole events. See CEPC Note http://cepcdoc.ihep.ac.cn/DocDB/0002/000203/002/CEPCNoteCover.pdf	With the support of the computing center of Institute of High Energy Physics, the CEPC samples are stored on the IHEP clusters.	manqi.ruan@ihep.ac.cn, ligang@ihep.ac.cn, yudan@ihep.ac.cn.	
FCC-ee	A limited number of useful e+e- event samples, processed through full CMS simulation and reconstruction, still exist (though producing again these events won't take very long).	On private areas	gerardo.ganis@cern.ch, clement.helsens@cern.ch, patrick.janot@cern.ch, patrizia.azzi@cern.ch	Same as FCC-hh (https://cds.cern.ch/record/2717892)
FCC-hh	Full and Delphes samples are listed here http://fcc-physics-events.web.cern.ch/fcc-physics-events/Delphesevents_fcc_v02.php http://fcc-physics-events.web.cern.ch/fcc-physics-events/FCCsim_v03.php	There are located on eos at CERN	Michele.Selvaggi@cern.ch, gerardo.ganis@cern.ch, clement.helsens@cern.ch	Yes, https://cds.cern.ch/record/2717892
LHeC/FCC-eh	Signal: several Higgs decay modes plus backgrounds	CERN and University servers	oliver.fischer@liverpool.ac.uk	No
Muon collider	Higgs to bb and b backgrounds	University of Padova Cloud	donatella lucchesi (donatella.lucchesi@pd.infn.it)	https://sites.google.com/site/muoncollider/home

Simulation Requirements

- Wide variety of studies anticipated within EF
  - Different types of MC needed for different purposes

accuracy

full sim

detector R&D/design
unconventional signatures
most-critical studies, i.e. Higgs couplings

Delphes/SGV

studies requiring large statistics
comprehensive surveys of machines

truth-level

speed

Charge of the EF MC Task Force (I)

1. Assess the MC needs for studies by each Energy Frontier Topical Group.
   a. This should include the processes, the MC generators, the accelerator configurations (c.o.m, integrated luminosity, pileup scenarios, if any), detector configurations, and number of events for each process type.
2. Survey existing frameworks for MC generation and analysis for future circular colliders (FCC-ee, FCC-hh, CepC, CppC, LHeC, EIC...etc...).
   a. Are the existing samples and framework sufficient for our studies?
   b. Need to request permission to use the existing samples?
3. Check/confirm that ILC, CLIC, Muon collider studies will use their frameworks, and no MC generation by EF group needs to be planned.
4. Finalize the plans and submit the recommendations by the end of June 2020 to the EF conveners.
5. The plan and recommendations will be presented to the EF community and discussed during the July 2020 EF Workshop.
6. The OSG has kindly agreed to support the MC generation for EF, and will provide both compute resources and storage on the OSG Data Federation.

8

[Narain]

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Community Survey

Collaboration Survey

8

collaboration and community surveys were distributed on May 31

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4. Finalize the plans and submit the recommendations by the end of ~~June~~ September 2020 to the EF conveners.
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Community Survey

Collaboration Survey

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collaboration and community surveys were distributed on May 31

Charge of the EF MC Task Force (II)

7. **Develop a plan,** in the event the EF group has to mount a production of a large set of samples for Standard Model backgrounds. The plan should address the following questions:
   a. Shall we adopt a “common framework” both for generation & analysis of the various samples, if so, which one(s)?
   b. Which samples are needed to be produced as a central production?
      i. Include detailed information about the samples (as listed in 1.a above).
      ii. Should signal samples be produced by the proponents and only large SM background samples be produced centrally?
   c. What scale of CPU resources are needed for sample generation?
   d. What projected size of storage is required for production and long term storage of the samples?
   e. Recommendation on the formation and activities of the “EF Monte Carlo Production team”.

9

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Community Survey

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Snowmass 2013

- Ran MadGraph5 + Pythia6 + Delphes3 opportunistically on the OSG to produce large-statistic SM background MC samples for future pp colliders

Parameter	LHC	HL-LHC	HE-LHC	VLHC
Energy [TeV]	14	14	33	100
Mean additional interactions per crossing ($< \mu >$)	50	140	140	140
Integrated Luminosity [fb^{-1}]	300	3000	3000	3000

- Documentation:
  - MC Simulation: https://arxiv.org/abs/1308.1636
  - “Snowmass” detector: https://arxiv.org/abs/1309.1057
  - OSG production: https://arxiv.org/abs/1308.0843

Snowmass 2013

- Signal MC production isn't resource intensive
  - Provided analysts with recipe for production from LHE, as well as analysis pointers
- Studies for ILC, CLIC, etc. used their own frameworks/samples
- Common data format for all future pp machines facilitated easy analysis/comparison
  - Tune a few cuts and turn the crank
- These samples were useful well beyond Snowmass itself
  - I am still occasionally asked if they are accessible

Event Generation

- With many background processes and E/PU combinations, adopted "container" scheme to simplify organization/book-keeping
  - Combined processes with similar cross sections in single MC sample
    - On-shell internal propagators excluded → fully orthogonal
  - On-shell heavy resonances treated as stable (decayed later w/ BRIDGE)
  - Up to 4 final state partons
- Each sample was binned in S_T^*: scalar p_T sum of all final state partons
  - One decade of cross section per bin (up to 7)

particle containers

$$
\begin{aligned}
J &= \{g, u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}, b, \bar{b}\} \\
L &= \{e^+, e^-, \mu^+, \mu^-, \tau^+, \tau^-, \nu_e, \nu_\mu, \nu_\tau\} \\
V &= \{W^+, W^-, Z^0, \gamma\} \\
T &= \{t, \bar{t}\} \\
H &= \{h^0\}
\end{aligned}
$$

MC samples

Dataset name	Physics process	Number of recoil jets
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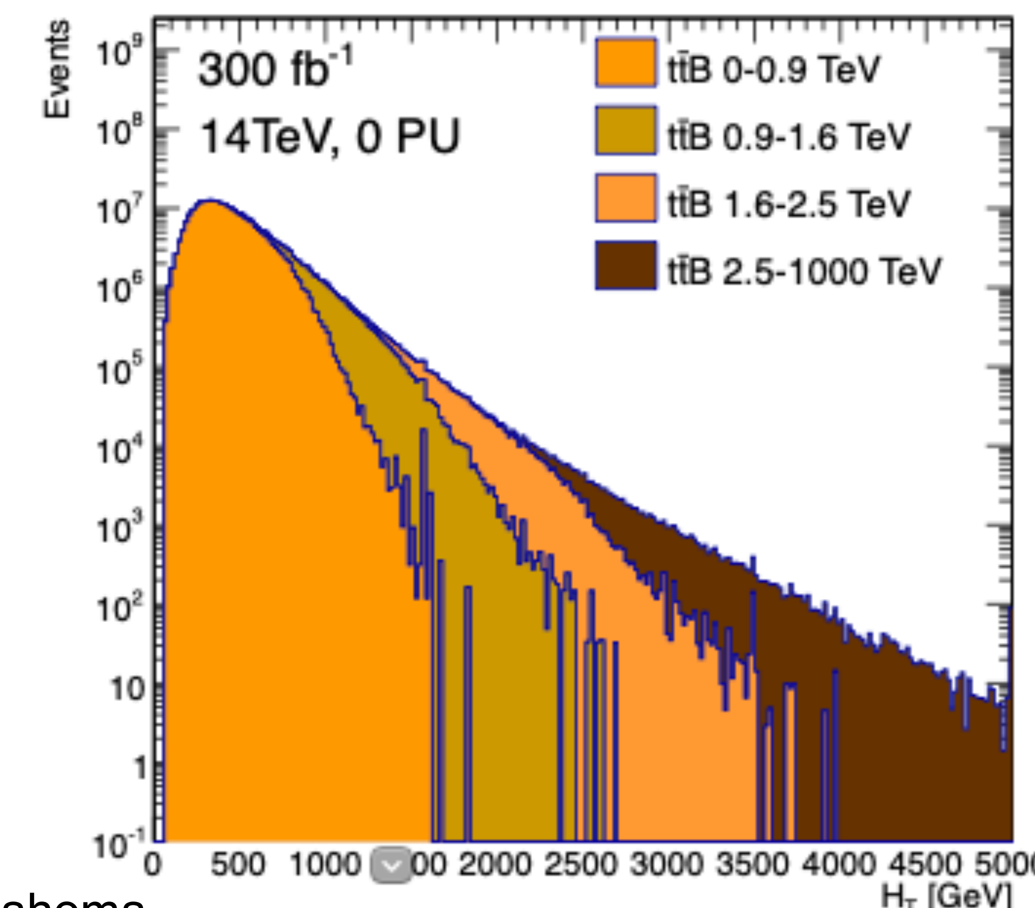
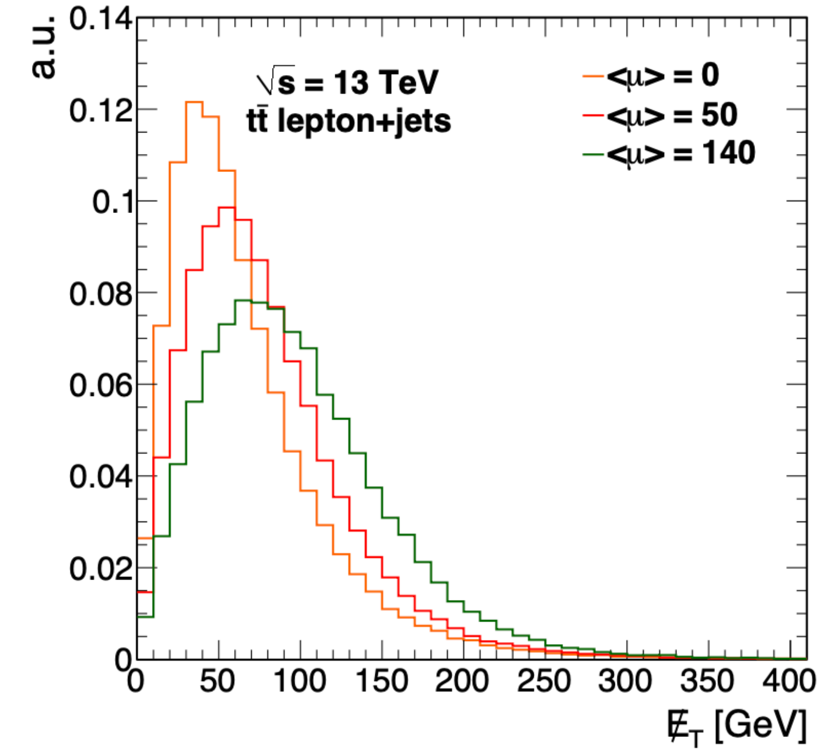
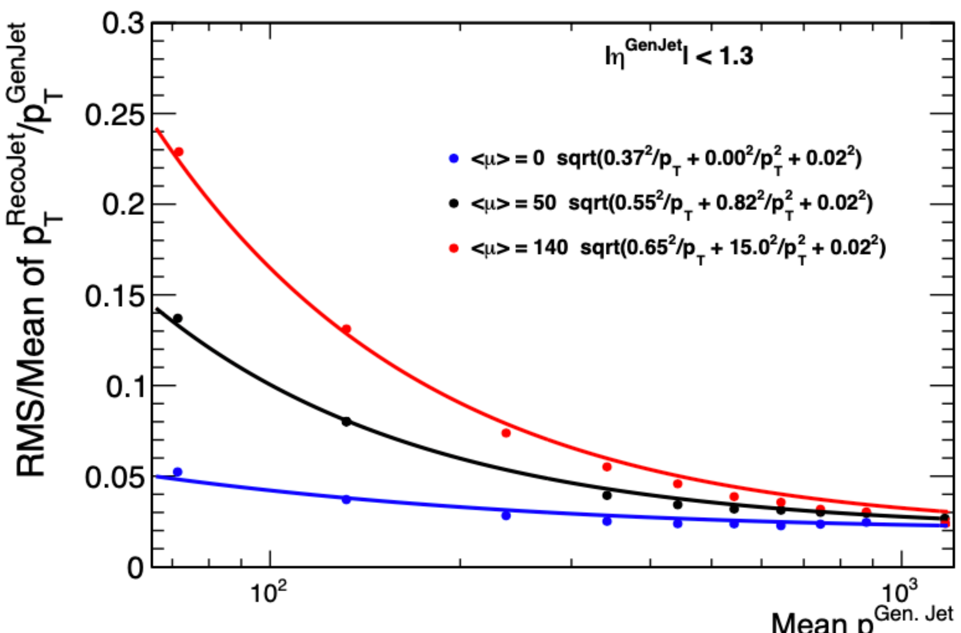
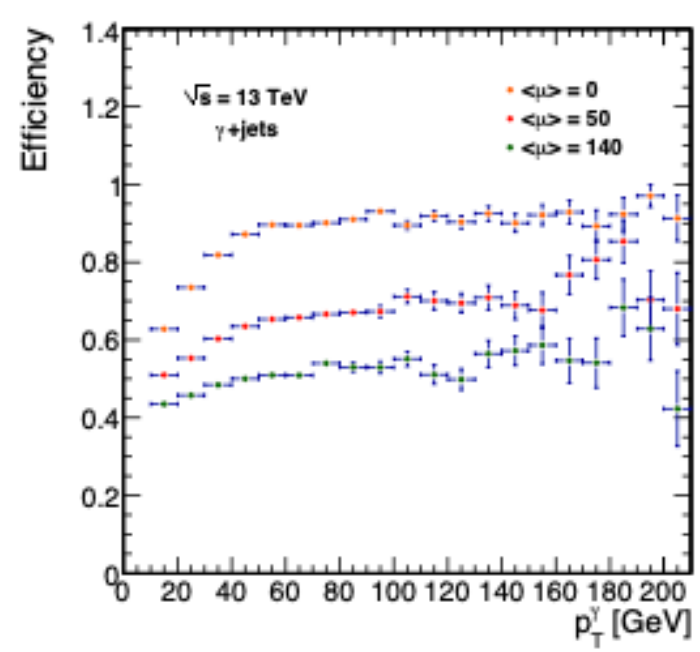


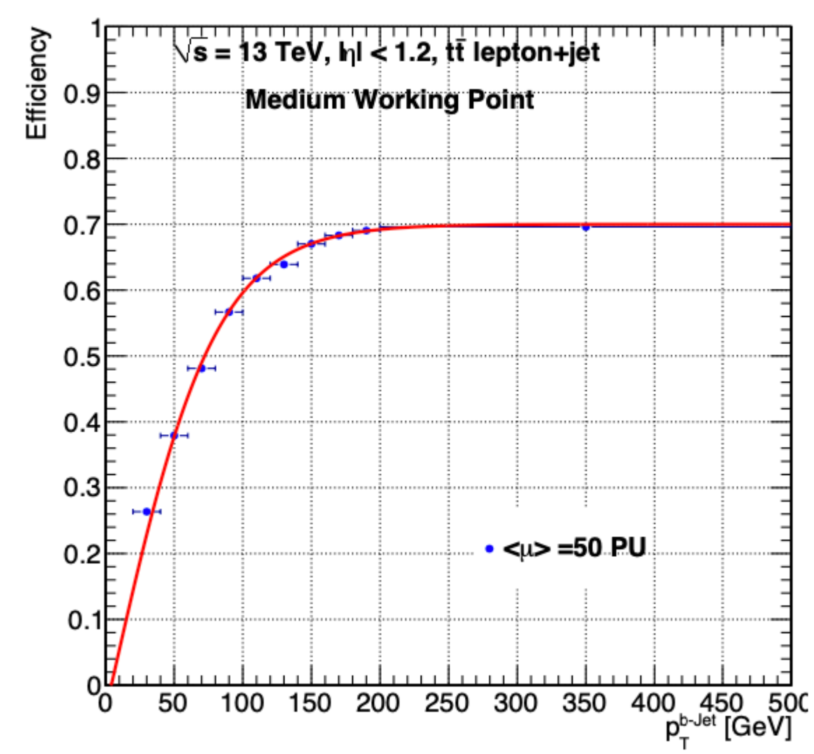
Detector Simulation/Reconstruction

- "Snowmass detector" implemented in Delphes
  - The best of both ATLAS and CMS
    - Performance taken from public documents, reflecting expected future upgrades
- Main simulation parameters (generally specified as p_T- and η-dependent functions):
  - Tracking efficiency (charged hadrons, e, μ)
  - Momentum resolution (charged hadrons, e, μ)
  - Calorimeter resolution (EM, hadronic clusters)
  - Reconstruction/tagging efficiency (e, μ, γ, b-jet, τ_h)
- Isolation determined by simulation
- PU suppression: charged hadron subtraction and area-based correction
- Developed new functionality (output slimming, jet grooming/substructure, t/V/H-tagging)









Event Weight

- Generator-level events produced at LO
  - NLO k-factor calculated from ratio of MCFM and MadGraph (inclusive) cross sections
- Used BRIDGE to decay heavy resonances democratically
  - Enhances statistics for rare decay modes
- σ_{LO} * k-factor * w_{BR} stored as event weight

Process	$\sqrt{s} = 14$ TeV	$\sqrt{s} = 33$ TeV	$\sqrt{s} = 100$ TeV
$t\bar{t}$	1.24	1.10	0.96
$W^+ j$	1.17	0.85	0.74
$W^- j$	1.20	0.89	0.75
$Z^0 j$	1.17	0.87	0.76
γj	1.54	1.04	0.89
$W^+ W^-$	1.25	1.08	1.0
$W^+ Z^0$	1.24	1.06	0.95
$W^- Z^0$	1.26	1.09	0.97
$Z^0 Z^0$	1.37	1.29	1.21
$W^+ \gamma$	1.22	0.80	0.67
$W^- \gamma$	1.33	0.83	0.67
$Z^0 \gamma$	1.24	0.95	0.76
$\gamma\gamma$	1.34	1.08	0.98
$t W^-$	1.0	0.77	0.78
$\bar{t} W^+$	1.0	0.77	0.78
$t\bar{b}$	1.76	1.72	1.94
$\bar{t} b$	1.88	1.73	1.78
$\ell^+ \ell^-$	1.20	1.16	1.20

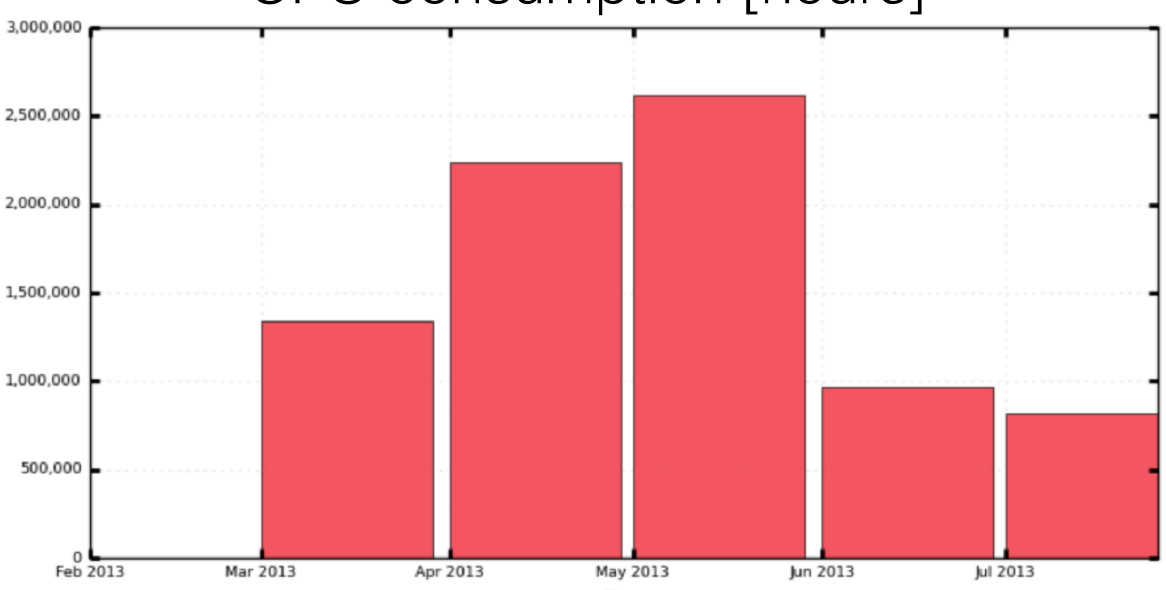
$t\bar{t} \to$	weight	in sample	change
hadronic	44%	25%	0.56
semi-leptonic	44%	50%	1.13
di-leptonic	11%	25%	2.25
$W^\pm Z^0 \to$	weight	in sample	change
1ℓ	30%	44%	1.4
2ℓ	6.7%	11%	1.6
3ℓ	3.3%	16%	4.8

Computing (OSG)

- Utilized opportunistic resources to produce ~0.5 billion events
  - ~14k jobs/day totaling ~890 CPU·years
  - Peak usage ≈ 100 kCPU·hours/day
- Job submission via GlideinWMS
- Software dependencies from CvmFS

- MadGraph and Pythia/Delphes performed in 2 separate jobs
  - MadGraph
    - ~10 MB input gridpack (output LHE) transferred via HTCondor
    - Responsible for most of the CPU usage
  - Pythia/Delphes
    - 1 GB minimum bias file pre-staged to storage nodes at 10 grid sites
    - Outputs (5-20 kB/event) transferred to FNAL, BNL, UNL
      - UNL was accessible (web and XRootD) without grid certificate (theorists)

CPU consumption [hours]



data transfer

Month	Fermi dCache (TB)	UNL (TB)
June	65.0	46.4
May	12.4	5.2
April	189.7	10.8
March	1.1	0.0
Total	268.3	62.5